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A *Jatropha* biomass as renewable materials for biocomposites and its applications

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ABSTRACT

This review deals with the study of *Jatropha* biomass as renewable materials for biocomposites and its applications. *Jatropha curcas* is a multipurpose plant with many attributes and considerable potential. *Jatropha* plant is cultivated worldwide but it has specific cultivation area in Central and South America, Africa, and South Asia. The *Jatropha* plant produces many useful products, especially the seed from which oil can be extracted. Extracted oil has similar properties to palm oil and possible to obtain many products after processing. As biomass, *Jatropha* plant can used as a reinforcement in biocomposite development. *Jatropha* contain high amount of carbon especially in seed/husk, fruit shell and seed cake and can be used as filler in composite fabrication in the form of carbon black and activated carbon.

In this review, we will discuss the distribution of *Jatropha* around the globe, chemical composition of various parts and extracts of *Jatropha* and their mechanical and physical properties. We will also cover the use of *Jatropha* biomass in various technical and biocomposite applications. With the development of green technology, *Jatropha* latex can be reduced to nanoparticle size. The chemical and physical properties of *Jatropha* contribute to its applications in food and non-food Products.

Contents

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1. Introduction

Much academic research and industrial development explore new ways to create greener and environmentally friendlier chemicals and materials for a variety of applications. Biocomposites are the combination of natural fibers (biofibers) such as wood fibers (hardwood and softwood) or non-wood fibers with polymer matrices from both renewable and nonrenewable resources. Researchers are trying to source for new alternative materials that can replace the existing products. Many government interventions and directives have also been launched in support to deal with this problem. Moreover, natural fiber-reinforced composites and technical application like resin, adhesive come from renewable materials and now, they can be obtained very easily. Biocomposite market is growing rapidly and so competition is expected among the industries to design superior strength biocomposites of commercial importance. The two main drawbacks of presently developed biocomposites from its rival glass fiber composites are poor moisture resistance and low impact strength. Recent research results show that there is a large potential in improving those two properties. This potential lays either in pre-treatment of the fibers, engineering of fibers or in improving the chemistry while impregnating the fibers with the matrix polymer. Our three-corner approach in designing biocomposites of superior/desired properties includes Bio-fiber treatment; Matrix modification and Novel Processing. Eco-friendly biocomposites from plant derived fiber and crop-derived plastics would be the novel materials of the 21st century not only as a solution to the growing environmental threat but also as a solution to alleviating the uncertainty of the petroleum supply which is expected to decline between 2010 and 2020 [1]

Following decades of development of artificial fibers, attention has been redirected onto the natural fibers such as flax, hemp, kenaf, sisal and jute. The advantages of natural fibers over synthetic or man-made fibers such as carbon and glass are the low density, low cost, acceptable specific strength properties, biodegradability, ease of separation, and carbon dioxide sequestration [2]. Natural composites are emerging as a viable alternative to glass fiber composites, particularly in automotive, packaging, building, and consumer product industries, and becoming one of the fastest growing additives for thermoplastics. The only source available today that focuses on bio-based materials, natural fibers, biopolymers, and biocomposites integrates the principles of sustainability, industrial ecology, eco-efficiency, and green chemistry and engineering into the development of the next generation of materials, products, and processes [1].

One of the plants that have many purposes is *Jatropha curcas* L. It is a tropical plant that can be grown in low to high rainfall areas. It can be used to reclaim land, as a hedge and/or as a commercial crop. It is one of the renewable resources, not only as bioenergy, but also for medical, food, and non-food application. *Jatropha* is a multipurpose species with many attributes and considerable potential. As biomass, *Jatropha* is attracting great attention over the world as a source of renewable energy as well as an alternative to fossil fuels. The *Jatropha* plant is currently receiving a lot of attention as an energy plant [3]. The shells of the seeds are promising to be an alternative fuel for India, China and Indonesia, as well as in South America and Africa, because they appear as a by-product during the processing of *Jatropha* oil and cannot used for any other application until now [4]. The technologies used to convert *Jatropha* into mainstream energy carriers have mainly concentrated on mechanical and chemical processes focusing on seed oil. However, *Jatropha* is a robust energy plant, which in addition to seed oil, also produces wood, fruit shells, seed husks and press-cake. These are potential sources of additional material carriers in a zero-waste biomaterial system for *Jatropha* [5].

In current research, beside *Jatropha* oil, the researcher concern *Jatropha* for many application such as purgative/laxative, and is widely known as medicinal for treatment of a variety of ailments. Preparations of all parts of the plant, including seeds, leaves and bark, fresh or as a decoction, are used in traditional medicine and veterinary purposes [6].

The latex of *Jatropha* contains alkaloids including jatrophine, jatropham and curcain [7]. The oil has a strong purgative action and is widely used to treat skin diseases and to soothe pain from rheumatism (Heller, 1996). The 36% linoleic acid (C18:2) content in *Jatropha* kernel oil is of possible interest for skincare [8].

The bark of *Jatropha* yields a dark blue dye which is reported to be used for coloring cloth, fishing nets and lines. The dye may be extracted from leaves and tender stems and concentrated to yellowish syrup or dried to blackish brown lumpy mass. The plants and fruit hulls could be used for firewood. Non-toxic variety of *Jatropha* could be a potential source of oil for human consumption, and the seed cake can be a good protein source for humans as well as for livestock [8]. The bark of *Jatropha* contains tannin. It can also have the honey production potential as the flowers can attract bees.

The glycerin by-product of the trans-esertification process can be used to make a high quality soap, or it can be refined and sold at a range of prices, depending on its purity, to be used in an immense range of products, including cosmetics, toothpaste, embalming fluids, pipe joint cement, cough medicine, and tobacco (as a moistening agent). The soap has positive effects on the skin and is therefore marketed for medicinal purposes. *Jatropha* oil is used mainly in the manufacture of high quality soap.

Jatropha seed cake contains curcin, a highly toxic protein similar to ricin in castor, making it unsuitable for animal feed. However, it does have potential as good organic manure replacing chemical fertilizer since it has nitrogen content [3]. Press-cake derived from the non-toxic varieties of *Jatropha* may be used as animal feed.

With the large number of product applications that has been done by researchers from different parts of the *Jatropha* plant, *Jatropha* as alternative biocomposite and product technical application needs to be further developed. The increasing areas of plantations of *J. curcas* in the world will lead to an increased amount of *J. curcas* in future. The purpose of this review is to provide information about its potential and current development in the field of *Jatropha* research, such as an alternative as biocomposite, natural fiber, nanotechnology and technical application (non-foot application).

2. Global distribution of *Jatropha*

Jatropha historically originates from Central America and the northern parts of South America origin with a history of cultivation in South Asia, India [9], Central and South America, and Africa[10–12] (Fig. 1).

The *Jatropha* can be grown in all countries falling under tropical, subtropical zones and in certain countries fall in temperate climate. Also in certain areas of Arid and sub-Arid regions As per vegetation classification it grows in the selva, or equatorial rain-forest belt, the hot tropical belt and in the savanna region perfectly. The number of countries that have planted the *Jatropha* is 48 African countries, 17 Asian countries, 24 North American counties and about 14 South American countries [13].

Starting from the 1980s *Jatropha* came to the attention of various NGOs addressing rural poverty in African and Asia. Because of its versatility, *Jatropha* is regarded as a useful crop in programs to alleviate rural poverty in developing economies; it has the virtue of being a highly suitable hedging material for containing stock and at the same time producing oil, which can be obtained by cold pressing for community use in heating/lighting/cooking and for powering simple agricultural equipment. On the basis of village scale cultivation of the crop for hedging or as an inter-row crop, *Jatropha* is also seen to have potential for providing the fuel stock for electricity generation [14]. *Jatropha* seeds were commercially produced on the Cabo Verde Islands already in 1836. The seeds were exported to Portugal and France and the oil was used for street lighting and soap production [15].

J. curcas L. is often referred to as '*Jatropha*'. The genus name *Jatropha* derives from the Greek *jatrós* (doctor), *trophé* (food), which implies medicinal uses [16]. *J. curcas* L. has many local name, *curcas* is the common name in Malabar, India, bagani (Ivory CoastMali), pourghère (French), physic nut (English), tabanani (Senegal), makaen/mmbono (Tanzania), piñon (Latin America), purgeernoot (Dutch), sketnoto (Surinamese) [8].

3. *Jatropha* plant

J. curcas is a small tree or large shrub with smooth gray bark, which exudates a whitish colored watery latex, upon cut [16]. It has large green to pale green leaves, alternate to sub-opposite, three to five lobed with a spirally phylotaxis. Different plant parts of *J. curcas* are shown in Fig. 2. It has up to 5 m height and belongs to the euphorbiaceae family [3,10]. The genus *Jatropha* contains approximately 175 known species [9,17].

The *Jatropha* plants start yielding from the second year of planting, but limited quantity [9,11]. The *J. curcas* plant has, however, high agro-industrial potential because of its various potentially beneficial products. The seeds of *Jatropha* are good source of oil, which can be used as a diesel substitute after transesterification. They are used also in medicines, and soap and cosmetics manufacture in various tropical countries. The residual



Fig. 1. Main distribution areas of *Jatropha curcas* (green) in the world. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

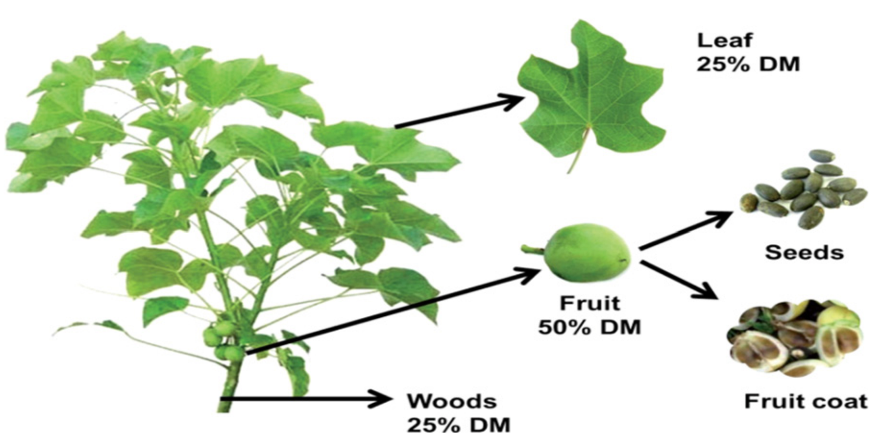


Fig. 2. Different components of *J. curcas*.



Fig. 3. Composition of *Jatropha* fruit.

Table 1
Chemical composition of different parts of *Jatropha* plant.

Various part	Chemical composition
Root	β-Sitosterol and its β-D-glucoside, marmesin, propacin, the curculathyranes A and B and the curcusones A–D, diterpenoids jatrophol and jatropholone A and B, the coumarin tomentin, the coumarino-lignan jatrophin as well as taraxerol
Stembark	β-Amyrin, β-sitosterol and taraxerol
Leaves	Flavaonoids apigenin, vitexin, isovitexin, dimmer of atriterpene alcohol ($C_{63}H_{117}O_9$) and two flavonoidal glycosides
Aerial parts	Organic acids (*o*- and *p*-coumaric acid, *p*-OH-benzoic acid, protocatechuic acid, resorsilic acid, saponins and tannins, β-amyrin, β-sitosterol and taraxerol
Latex	Curcacycline A, a cyclic octapeptide, Curcain (a protease)
Seeds	Curcin, lectin, phorbol esters, esterases (JEA) and lipase (JEB)
Oil cake and kernel	Phytates, saponins and trypsine inhibitor

Adopted from [3].

protein-rich seed cake, remaining after extraction of the oil, could from a protein-rich ingredient in feeds for animal if it could be detoxified [10].

Traditionally, *Jatropha* is used to prevent and/or to control erosion, to reclaim land or to act as a living fence for excluding farm animals [18]. Many plant parts have potential medicinal and commercial value, such as tannin from the bark for treating leather, honey from its flower, and *Jatropha* stem latex as a source of pharmaceutical components [19]. *Jatropha* leaves can be used for silkworm feed, antiseptics, or remedy for dermatitis [19]. *Jatropha* fruit coat is a sugar-rich material and can be used as a green fertilizer or for biogas production. *Jatropha* seed contains about 30–40% oil [5,8,20], which has similar fatty acids composition.

On average the *Jatropha* fruits are 2.5 cm long, ovoid and each fruit contains 2–3 seeds. It has nearly 400–425 fruits per kg and 1500–1600 seeds per kg weight [9]. Dry *Jatropha* fruit contains about 35–40% shell and 60–65% seed by weight [11]. The seed is made up of about 42% husks and 58% kernel [9]. On fruit weight basis, *Jatropha* contains about 17–18% oil [9] and seeds contain up to 34% oil. The seed contains about 42% hull/husk and 58% kernel [9]. Composition of *Jatropha* fruit in Fig. 3.

3.1. Chemical composition of different parts of Jatropha

To identify the parts of the *Jatropha* plant then it need to know the physical and chemical properties of these plants. This needs to be done in order to identify products that will be made easier. *Jatropha* is a multipurpose shrub of significant economic importance because of its several potential industrial. Chemical composition of different parts of *Jatropha* plant is given in Table 1 [3,21]. Kumar and Sharma [3] have concluded chemical composition all part of *Jatropha* plant to investigated the compounds in root, stembark, leaves, areal parts, latex, seed, oil cake and kernel from many literatures. All parts of *Jatropha* plant have chemicals and can used for many applications.

Chemical composition from *Jatropha* plant parts depends on the moisture content, lignin, cellulose, volatile solid and ash with pH and ratio carbon toward nitrogen have investigated by Nallathambi Gunaseelan [22] in Table 2.

The chemical composition of protein in *Jatropha* plant parts summaries in Table 3. Much research has been conducted to extract protein from *Jatropha* plant in combination with a detoxification process to produce protein concentrates or protein isolates for animal feed [27]. Just view literature studied *Jatropha* meal utilization for non-food applications, such as adhesives, coatings, and surfactants. Protein content previously reported in *Jatropha* was often different because of differences in cultivars of *Jatropha*, *Jatropha* growth conditions, climate and soil conditions, *Jatropha* seed part, and oil extraction methods.

Table 2
Chemical composition of *Jatropha* plant parts.

Part of *Jatropha*	Moisture Content (%)	VS (%TS)	pH	C/N ratio	Acid-detergent fiber		
					Lignin (gg^{-1} VS)	Cellulose (gg^{-1} VS)	Ash (gg^{-1} VS)
Jatropha curcas L. mature leaf lamina	73.6 (0.9)	90.2 (0.1)	6.91 (0.02)	9.7 (0.6)	0.200 (0.002)	0.310 (0.005)	0.01 (0.002)
Mature leaf petiole	87.3 (0.3)	89.4 (0.1)	5.91 (0.05)	24.1 (0.7)	0.134 (0.001)	0.324 (0.006)	0.01 (0.001)
Mature leaf entire	78.5 (0.8)	88.4 (1.0)	5.77 (0.07)	9.4 (1.1)	0.180 (0.001)	0.338 (0.008)	0.006 (0.001)
Tender leaf entire	74.4 (0.5)	90.0 (0.2)	6.43 (0.03)	7.1 (0.4)	0.144 (0.005)	0.344 (0.015)	0.00
Green fruit	89.1 (0.2)	93.0 (1.1)	5.27 (0.08)	14.3 (0.9)	0.090 (0.004)	0.301 (0.015)	0.02 (0.001)
Yellow fruit	86.7 (0.6)	92.0 (0.7)	5.81 (0.07)	10.1 (0.5)	0.098 (0.001)	0.326 (0.013)	0.005 (0.001)
Brown fruit	8.8 (0.1)	92.8 (0.2)	6.51 (0.05)	12.5 (1.1)	0.097 (0.001)	0.302 (0.006)	0.02 (0.001)
Fruit hull	12.2 (0.1)	91.6 (0.3)	6.26 (0.02)	30.4 (0.6)	0.142 (0.003)	0.393 (0.008)	0.01 (0.001)
Seed testa	10.1 (0.2)	96.2 (0.1	7.34 (0.01)	32.1 (0.5)	0.083 (0.007)	0.624 (0.009)	0.01 (0.005)
Seed kernel	5.2 (0.1)	95.6 (0.1)	6.23 (0.03)	17.1 (0.3)	0.052 (0.003)	0.274 (0.007)	0.00
Seed entire	8.9 (0.1)	95.0 (0.3)	6.63 (0.07)	13.9 (0.7)	0.042 (0.008)	0.274 (0.009)	0.01 (0.002)
De-oil cake	5.9 (0.09)	89.2 (0.5)	5.32 (0.08)	17.7 (0.9)	0.056 (0.005)	0.369 (0.005)	0.02 (0.002)

Table 3
Chemical composition of *Jatropha* protein (on dry matter basis).

Jatropha parts	Crude fat	Crude fiber	Crude ash	Crude protein	Reference
Seed cake	14.8 ± 0.5 (% w/w)	11.0 ± 1.7 (% w/w)	7.8 ± 0.1 (% w/w)	23.5 ± 1.5 (% w/w)	[23]
	60 (gr kg^{-1} dm)	–	167 (gr kg^{-1} dm)	244 (gr kg^{-1} dm)	[27]
	–	–	–	22.9 ± 0.03 (%)	[24]
Seed cake protein isolate	8.6 ± 0.2 (% w/w)	0.27 ± 0.06 (% w/w)	1.8 ± 0.1 (% w/w)	90.1 ± 0.8 (% w/w)	[23]
	–	–	–	72.6 ± 0.54 (% w/w)	[24]
Seed of *Jatropha* platyphila	80 (gr kg^{-1} dm)	–	87 (gr kg^{-1} dm)	361 (gr kg^{-1} dm)	[25]
Kernel	56.8–58.4 (%)	–	3.6–4.3	22.2–27.2	[26]
Shell	0.5–1.4	–	2.8–6.1	4.3–4.5	[26]
Meal	1.0–1.5	–	9.6–10.4	56.4–63.8	[26]
Leaves	8.2 (% w/w)	–	12.0 (% w/w)	20.6 (% w/w)	[24]

3.1.1. Chemical composition of Jatropha leaves

Besides *Jatropha* seed or press cake, *Jatropha* leaves could be exploited as a protein source. In addition, leaf proteins are potential sources for amino acids, which can be converted into functionalized bulk chemicals. Currently, the uses and characteristics of *Jatropha* leaf protein have been investigated by Lestari [24]. The chemical composition of *Jatropha* leaf is shown in Table 4. From [24], it is known that acid insoluble lignin (24% w/w dry matter) and protein (21% w/w dry matter) were the major components in *Jatropha* leaf. Carbohydrates in leaf were present in the form of soluble sugar (15% w/w dry matter) and polysaccharide (10% w/w dry matter). After strong acid hydrolysis, about 65% w/w of polysaccharide was converted to glucose. *Jatropha* leaf contained high contents of ash, soluble sugar and lignin. Based on this, the method to extract and purify protein from *Jatropha* leaves should involve dialysis to remove salts and acid washing to remove acid insoluble lignin.

Table 4
Chemical composition of *Jatropha* leaf.

Component	Compositions (% weight dry basis)
Fat	8.2
Crude protein	20.6
Carbohydrate	
Soluble sugar	15.3
Polysaccharide	10.2
Arabinose	0.6
Xylose	1.0
Mannose	0.6
Galactose	1.5
Glucose	7.1
Pectin	3.9
Lignin	
Acid insoluble lignin	23.5
Acid soluble lignin	2.8
Ash	12.0

Adopted from [24].

3.1.2. Chemical composition of Jatropha seed

The seeds of *Jatropha* are used traditionally for wound-healing, fractures and burns. In recent reports seed polysaccharides from other plant sources as e.g. arabinogalactans [28] and rhamnogalacturonans have been reported to exceed strong influence on the cell physiology of dermal fibroblasts and keratinocytes and to enhance formation of extracellular matrix proteins. Zippel et al. [12] have investigated potential in vitro effects of the polysaccharides from *Jatropha* on skin cells in in vitro monolayer cell cultures and in complex organotypic skin equivalents. Carbohydrte and amino acid composition from *Jatropha* seed in %-values refer either to the total carbohydrate or the total protein content of *Jatropha*. Carbohydrates as determined by HPAEC-PAD after TFA hydrolysis against external standard calibration and amino acids by HPAEC-PAD against external standard calibration after hydrolysis with 6 M HCl, 110 °C, 6 h; tryptophan were determined after hydrolysis with 4.25 M NaOH, 110 °C, 20 min in Table 5. The resulting protein depleted polysaccharide fraction was named JC (yield 0.98% related to the endosperm material).

3.1.3. Chemical composition of Jatropha oil

Depending on the variety, the decorticated seeds contain 40–60% of oil [18,19,29], which is used for many purposes such as lighting, as a lubricant, for making soap and most importantly as biodiesel. Seeds contain different kinds of saturated and

unsaturated fatty acids. The oil fraction of *Jatropha* contains saturated fatty acids mainly palmitic acid (C16:0) and stearic acid (C18:0). Unsaturated fatty acids consisted of oleic acid (C18:1) and linoleic acid (C18:2). The oil with high percentage of monounsaturated oleic and polyunsaturated linoleic acid has a semi-drying property (partially hardens when the oil is exposed to air). This semi-drying oil could be an efficient substitute for diesel fuel. Treatment of plants with growth regulators significantly influenced the production of hydrocarbons [30].

The fatty acid composition of the *Jatropha* oil with palm, coconut, sunflower, soybean oil and pongamia oil, compared with the reported values, is given in Table 6. The fatty acids found common in all the oil samples were oleic, linoleic, palmitic and stearic. The results showed that the oil is composed mainly of unsaturated fatty acids (oleic and linoleic acid). Chemical and physical properties of *Jatropha* oil are given in Table 7.

3.2. Physical and mechanical properties of Jatropha plant

Physical and mechanical properties of *Jatropha* fruit, shell and kernel (Table 8) are important to design equipments for dehulling, nut shelling, drying and oil extraction, and also in other processes like, transportation and storage. Size and shape of the fruit, shell and kernel are important for designing the dehulling or nut shelling machine, and data on them can be used to determine the lower size limit of the conveyors such as belt conveyor, bucket elevator and screw conveyor. Porosity (calculated from solid density and bulk density), surface area and specific surface area affect the resistance to airflow through the bulk material bed and data on them are necessary in designing the drying process. Bulk density is used in determining the size of the storage bin. Moisture content is a useful information in the drying process. Static friction coefficient of various surfaces affects the maximum inclination angle of conveyor and storage bin. The magnitude of frictional force affects the amount of power required to convey the materials. Angle of repose is a useful parameter for calculation of belt conveyor width and for designing the shape of storage. Mechanical properties such as rupture force, hardness and energy used for rupturing fruit, shell and kernel are useful information in designing the dehulling or nut shelling machine and oil extractor. The rupture force indicates the minimum force required for dehulling the fruit or shelling the nut and to extract the oil from kernel. The deformation at rupture point can be used for the determination of the gap size between the surfaces to compress the fruit or shell for dehulling or shelling [32].

Table 5
Carbohydrate and amino acid composition of JC from *J. curcas* seed endosperm.

Carbohydrate monomer	JC (mol%)	Carbohydrate monomer	JC (mol%)
Fucose	1.1	Mannose	4.0
Rhamnose	9.9	Xylose	3.5
Arabinose	27.9	Ribose	4.9
Galactose	33.4	Galacturonic acid	2.7
Glucose	11.9	Glucuronic acid	0.7
Amino acid	**JC (mol%)**	**Amino acid**	**JC (mol%)**
Arginine	7.5	Isoleucine	5.4
Lysine	9.7	Leucine	8.4
Glutamine	10.2	Methionine	0.3
Alanine	11.0	Histidine	3.5
Threonine	4.2	Phenylanine	2.8
Glicine	10.1	Glutamate	1.9
Valine	6.4	Aspartate	1.4
Hydroxyproline	0.3	Cystine	3.1
Serine	7.6	Tyrosine	0.8
Proline	4.0	Tryptophane	1.2

Adopted from [12].

Table 7
Chemical and physical properties of *Jatropha* oil.
Source: Giibitz et al. [32].

Parameter	*Jatropha* oil
Density at 15 °C	0.920 gr/cm^3
Viscosity at 30 °C	52 cSt
Flash point	240 °C
Fire point	274 ± 3 °C
Cloud point	9 ± 1 °C
Pour point	4 ± 1 °C
Cetane number	38
Caloric value	38.20 Mj/kg
Conratson carbon residue	0.8 ± 0.1 (% w/w)
Hydrogen	10.52 (% w/w)
Sulfur	0 (% w/w)
Oxygen	11.06 (% w/w)
Nitrogen	0
Carbon	76.11 (% w/w)
Ash content	0.03 (% w/w)
Neutralization number	0.92 mg KOH/gr
Saponification value	198.00
Iodine number	94
Monoglycerides	Not detected
Digliccrides	2.7% m/m
Triglycerides	97.3% m/m
Water	0.07% m/m
Phosphorus	290 mg/kg
Calcium	56 mg/kg
Magnecium	103 mg/kg
Iron	2.4 mg/kg

Table 6
Chemical composition comparison of fatty acid profile.

Fatty acid	*Jatropha* oil[a]	Palm oil[a,b]		Coconut oil[b]	Sunflower oil[b]	Soybean oil[b]	Pongamia (karanja oil)[b]
Caprylic acid (C8:0)	–	–		8	–	–	–
Capric acid (C10:0)	–	–		8	–	–	–
Lauric acid (C12:0)	–	–	–	48	0.5	–	–
Myristic acid (C14:0)	0.38	3.5	–	16.0	0.2	0.1	–
Palmitic acid (C16:0)	16.0	39.5	40.3	8.5	4.8	11.0	9.8
Palmetoleic acid (16:1)	1–3.5	–	–	–	0.8	0.1	–
Stearic acid (C18:0)	6–7	3.5	3.1	2.5	5.7	4.0	6.2
Oleic acid (C18:1)	42–43.5	46	43.3	6.5	20.6	23.4	72.2
Linoleic acid (C18:2)	33–34.5	7.5	13.2	2.0	66.2	53.2	11.8
Linolenic acid (C18:3)	0.8	–	–	–	0.8	7.8	–

[a] Adapted from [16].
[b] Adapted from [31].

Table 8
Physical and mechanical properties of *Jatropha* fruits, seed and kernel.

Propeties	*N*	Fruit	Seed	Kernel
1000-unit mass, g	100	14,560.9 ± 2412.4	1322.4 ± 14.6	688.1 ± 5.7
Seed fraction, %	3	24.53		
Kernel fraction, %	3	12.63		
Shell fraction, %	3	11.90		
Hull fraction, %		75.47		
Length, mm	100	33.36 ± 1.58	21.02 ± 1.03	15.45 ± 0.54
Equatorial width perpendicular to the length, mm	100	30.05 ± 1.08	9.58 ± 0.28	7.42 ± 0.33
Breadth perpendicular to the length and width, mm	100	31.51 ± 0.97	11.97 ± 0.30	10.25 ± 0.36
Geometric mean diameter, mm	100	31.60 ± 1.01	13.40 ± 0.36	10.55 ± 0.34
Sphericity	100	0.95 ± 0.03	0.64 ± 0.03	0.68 ± 0.01
Bulk density, g/cm^3	3	0.47 ± 0.00	0.45 ± 0.01	0.42 ± 0.01
Solid density, g/cm^3	20	0.95 ± 0.02	1.04 ± 0.04	1.02 ± 0.05
Porosity, %	NA	50.53	56.73	58.82
Surface area, mm^2	100	3139.21 ± 197.41	534.12 ± 31.81	306.48 ± 22.08
Specific surface area, cm^2/cm^3	100	0.90 ± 0.07	1.91 ± 0.12	2.12 ± 0.08
Coefficient of static friction on various surface				
Ply wood	3	0.50 ± 0.05	0.49 ± 0.03	0.72 ± 0.06
Steel	3	0.64 ± 0.05	0.46 ± 0.01	0.73 ± 0.03
Stainless steel	3	0.46 ± 0.02	0.49 ± 0.04	0.65 ± 0.02
Angel of repose				
Filling method	3	53.53 ± 1.72	54.00 ± 5.13	60.23 ± 6.16
Emtying method	3	42.91 ± 0.67	37.76 ± 2.85	42.92 ± 0.82
Rupture force, N	20	135.39 ± 54.86	146.63 ± 14.82	67.72 ± 19.03
Deformation at rupture point, mm	20	4.36 ± 1.42	2.10 ± 0.19	1.74 ± 0.37
Deformation ratio at rupture point, mm	20	0.15 ± 0.05	0.22 ± 0.02	0.23 ± 0.05
Hardness, N/mm	20	30.58 ± 5.88	69.98 ± 6.22	38.52 ± 5.59
Energy used for rupture, N mm	20	300.88 ± 237.84	124.44 ± 19.95	51.61 ± 26.84

N is a number of samples. Data, a mean values ± standard deviation. NA is not applicable.
Adopted from [33].

4. *Jatropha* biomass as renewable materials for biocomposite fabrication

Biocomposites are composite materials comprising one or more phase(s) derived from a biological origin. In terms of the reinforcement, this could include plant fibers such as cotton, flax, hemp and the like, or fibers from recycled wood or waste paper, or even by-products from food crops. Regenerated cellulose fibers (viscose/rayon) are also included in this definition, since ultimately they too come from a renewable resource, as are natural 'nano-fibrils' of cellulose and chitin. Matrices may be polymers, ideally derived from renewable resources such as vegetable oils or starches. Alternatively, and more commonly at the present time, synthetic, fossil-derived polymers preponderate and may be either 'virgin' or recycled thermoplastics such as polyethylene, polypropylene, polystyrene and polyvinyl chloride, or virgin thermosets such as unsaturated polyesters, phenol–formaldehyde, isocyanates and epoxies [34].

Biopolymers/biomatrices (biodegradable polymers) may be obtained from renewable resources, synthesized microbially, or synthesized from petroleum-based chemicals. Through blend of two or more biopolymers a new biopolymer may be designed for specific requirements. Thus biodegradability is not only a function of origin but also of chemical structure and degrading environment. Biodegradable polymers may be defined [35] as those that undergo microbially induced chain scission, leading to mineralization, photodegradation, oxidation, and hydrolysis, which can alter the polymer during the degradation process. Another definition states that biodegradable polymers are capable of undergoing decomposition, primarily through enzymatic action of microorganisms in to CO_2, methane, inorganic compounds, or biomass, in a specified period of time.

Biodegradable polymers need to be developed so as to make them suitable as matrix polymers for composite applications. Traditional plastics, such as polypropylene, polyethylene, polyester, and epoxy, have undergone considerable development and wide use in composite applications. Originally, biopolymers were intended to be used in packaging industries, farming, and other applications with minor strength requirements. Performance limitations and the high cost of biopolymers are major barriers for their widespread acceptance as substitute for traditional nonbiodegradable polymers. The high performance of traditional plastic is the outcome of years of research however, biopolymers are now of interest because of the current environmental threat and societal concern. The high cost of biopolymers compared to traditional plastics is not due to the raw material costs for biopolymer synthesis; rather it is mainly attributed to the low volume of production. New and emerging applications for biopolymers will result in increased production. The challenge for the development of biodegradable polymers lies in the fact that such biopolymers should be stable during storage or usage and then degrade once disposed of after their intended lifetime. Biopolymers on reinforcement with biofibers can produce novel biocomposites to replace/substitute glass fiber-reinforced composites in various applications.

Biopolyesters such as PLA and PHA are attracting much attention as promising biopolymers. PLA is a highly versatile biopolymer and is highlighted because it is derived from a renewable resource such as corn [36]. The use of products such as PLA as a cost-effective alternative to commodity petroleum-based plastic will increase the demand for agricultural products. The CagillDow plant in Nebraska is capable of producing 300 million pounds of renewable resource-based PLA per year (the plant became fully operational in January 2002) and uses up to 40,000 bushels of locally grown corn per day as the raw material for the manufacturing process. Biocomposites from natural fiber and PLA are attracting recent research interest [37]. The bacterial polyesters, e.g., PHA, have attracted recent attention as promising biopolymers in view of Metabolix's venture to make such biopolymers directly in plants [38]. Direct production of PHAs in plants

would yield economics competitive with those of existing large-volume petrochemical polymers. In other words, the low costs achievable with plant crop production of PHAs will allow polymers, materials, and chemicals derived from them to serve as realistic, cost-effective, sustainable alternatives to many of the largest-volume plastics and chemicals now made by the petrochemical industry.

Fibers provide strength and stiffness and act as reinforced composite materials; ultimately the properties of a composite are governed by the inherent properties of these fibers. The properties of natural fibers mainly depend upon its chemical composition. Chemical composition of fibers depends on various factors. It varies with the geographic location, climate, type of fiber, plant part and soil conditions, etc. [39].

The matrix in a fiber-reinforced composite holds the fiber together, transfers applied loads to those fiber and protecs them from mechanical damage and other environmental factors. *Jatropha* plant as woody plant has many purposes in parts of the plant. Depend on the chemical and physical properties, Jatropha plant has potential as biocomposite reinforcement/filler.

4.1. Jatropha based biocomposites

Composite manufacturing industries have to look for plant based natural fiber reinforcements, such as *Jatropha* plant as an alternative material which is going to replace solid wood. Natural fibers can be classified into plant-based and animal-based fibers. To be used as reinforcement, pure fibers need to be extracted and separated from all cementing substances that are present in the natural plant or animal raw material (hemicelluloses, lignin, wax, proteins, etc.). Plant fibers include bast (or stem or soft sclerenchyma) febres, leaf or hard fibers, seed, fruit, wood, cereal straw and other grass fibers. In general, plant-based natural fibers are lignocellulose in nature composed of cellulose, hemicellulose, and lignin, whereas animal based fibers are of proteins, e.g., silk and wool. Wood, that is, a fibrous composite in itself is commonly used in the form of wood pulp [40,41]. Wood is natural three-dimensional polymeric composite and consists primarily of cellulose, hemicellulose and lignin. In addition, wood is an original and natural composite [42]. Natural plant fibers constitute of cellulose fibers, consisting of helically wound cellulose microfibrils, bound together by an amorphous lignin matrix [43].

Natural fibers have so many advantages such as abundantly available, low density, low cost, low weight [44–47], biodegradable, cheaper, renewable, low abrasive nature, interesting specific properties, as these are waste biomass and exhibit good mechanical properties [43]. However, the main disadvantages of natural fibers in composites are the poor compatibility between fiber and matrix and the relative high moisture sorption [44–47]. Lignocellulosic natural fibers such as sisal, coir, jute, ramie, pineapple leaf (PALF), and kenaf have the potential to be used as a replacement for glass or other traditional reinforcement materials in composites [48]. These fibers have many properties which make them an attractive alternative to traditional materials [49].

A better understanding of the chemical composition and surface adhesive bonding of natural fiber is necessary for developing natural fiber-reinforced composites. The components of natural fibers include cellulose, hemicellulose, lignin, pectin, waxes and water soluble substances. Mechanical properties of these fibers are dependent on the cellulose content in the fiber, the degree of polymerization of the cellulose and the micro fibril angle. Fibers with higher cellulose content, higher degree of polymerization and a lower microfibrillar angle exhibit higher tensile strength and modulus. These fibers exhibit variations in mechanical properties both along the length of an individual fiber and between fibers. Hemicelluloses act as a matrix for the cellulose. It is supposed to act as a link between the fibrous cellulose and the amorphous lignin. Lignin is a phenolic compound that holds the fibers together. Lignin acts as a stiffening agent for the cellulose molecules within the fiber cell walls. All three cell wall components contribute in different extents to the strength of fiber [39].

No research about biocomposite from *Jatropha* plant. During this time, *Jatropha* research focused on biodiesel and medicine. As of woody plant, *Jatropha* have lignocellulose compounds. The composition of selected natural fibers is shown in Table 9 [45,46] and also *Jatropha* composition in many literatures.

Cellulose is the basic structural component of all plant fibers [49,55]. It is the most important organic compound produced by

Table 9
The composition of difference plant of natural fiber.

Type of fiber		Cellulose (%)	Lignin (%)	Hemicellulose (or pentosan) (%)	Pectin (%)	Ash (%)	Reference
A	Bast fiber						[45]
	Fiber flax	71	2.2	18.6–20.6	2.3	–	
	Seed flax	43–47	21–23	24–26	–	5	
	Kenaf	31–57	15–19	21.5–23	–	2–5	
	Jute	41–71.5	12–26	13.6–21	0.2	0.5–2	
		60	15.9	22.1	–	1	
	Hemp	57–77	3.7–13	14–22.4	0.9	0.8	[49]
	Ramie	86.6–91	0.6–0.7	5–16.7	1.9	–	[45]
B	Core Fiber						[45]
	Kenaf	37–49	15–21	18–24	–	2–4	
	Jute	41–48	21–24	18–22	–	0.8	
C	Leaf fiber						[45]
	Abaca	56–63	7–9	15–17	–	3	
	Sisal	47–78	7–11	10–24	10	0.6–1	
	Henequen	77.6	13.1	4–8	–	–	
	Jatropha hulk	42.8–43.3	9.6–10.2	14.7–15.2	–	–	[50]
	Wood component of *Jatropha* shell	22.29	47.60	23.84	–	–	[51]
	Jatropha Stem	42.99	24.11	19.11	–	–	[52]
	Jatropha fruit shell	33.75	11.90	9.70	–	–	[9]
	Jatropha waste	56.31	23.91	17.47	–	–	[53]
	Jatropha fruit coat	13.11	28.91	7.69	–	–	[54]
	Sugar cane bagasse	54.3–55.2	24.3–25.3	16.8–29.7	–	1.1	[49]
	Leaflet of phoenix dactilyvera palm	33.5	27	26	–	6.2	[49]
	Rachis of phoenix dactilyvera palm	44	14	28	–	2.5	[49]
	Cotton lintners	90	–	6	–	–	[49]

plants and the most abundant in the biosphere. The cellulose molecules consist of glucose units linked together in long chains, which in turn are linked together in bundles called microfibrils (Fig. 4, scheme of the cellulose cell wall and microfibril organization [48]). The tensile strength of the cellulose microfibrils is enormous, being the strongest known material with a theoretically estimated tensile strength of 7.5 GPa [55].

Hemicelluloses are also found in all plant fibers. Hemicelluloses are polysaccharides bonded together in relatively short, branching chains. They are intimately associated with the cellulose microfibrils, embedding the cellulose in a matrix [53,54]. Hemicelluloses are very hydrophilic (i.e., containing many sites to which water can readily bond) [55].

Lignin is the compound which gives rigidity to the plant. Lignin is a three-dimensional polymer with an amorphous structure and a high molecular weight. Of the three main constituents in fibers, it is expected that lignin would be the one with least affinity for water. Another important feature of lignin is that it is thermoplastic (i.e., at temperatures around 90 °C it starts to soften and at temperatures around 170 °C it starts to flow) [55].

Jatropha is a woody plant and, therefore, its twigs, branches and stems can be used for a number of purpose, and as an alternative for biocomposite. The cellulose, hemmicellulose, and lignin component in part of *Jatropha* such as bark, stem, seed, seed shell have the same component with any other plant (in Table 7). They can used to make fiber as composite reinforcement.

4.1.1. *Jatropha* oil cake incorporated glass–epoxy composites

An investigation was made to evaluate the effect of the incorporation of *Jatropha* oil cake (JOC) alone and in combination with silicon carbide (SiC) on the mechanical and tribological wear behavior of glass fabric–epoxy (GE) composites. A vacuum-assisted resin transfer molding (VARTM) technique was employed to obtain a series of GE composites containing different fillers viz., silicon carbide, *Jatropha* oil cake and a mixture of SiC and JOC. The effect of different loads (22 and 32 N) and abrading distances from 135 to 540 m on the performance of the wear resistance of the composites were measured.

The mechanical properties such as tensile behavior and hardness of the composites were evaluated. A linear relationship was found between the wear volume loss and the abrading distances. The JOC filled GE composite exhibited a lower specific wear rate by 6% and 10% at 540 m abrading distance for a load of 22 and 32 N, respectively, as compared to that of unfilled GE composites. The worn surface features of unfilled and filled GE composites were examined using scanning electron microscopy (SEM).

A significant difference between the SEM images of unfilled and JOC filled GE composite could be observed. Both at high and at low abrading distances, the JOC filled GE composite (Fig. 5a,b) exhibited relatively less fiber opening and fiber fracture compared to the unfilled GE composite. The SEM images of the GE composite containing a mixture of SiC and JOC (Fig. 6a,b) revealed a better and improved abrasion resistance compared to unfilled and JOC

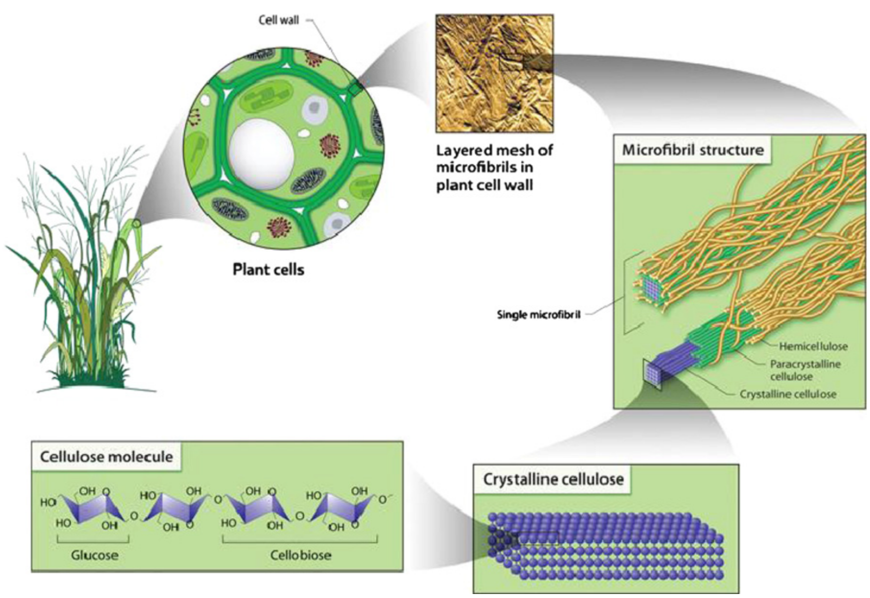


Fig. 4. Scheme of the cellulose cell wall and microfibril organization [49].

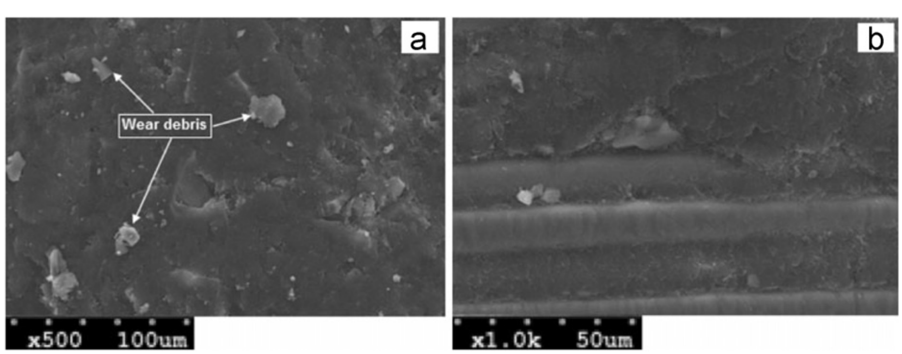


Fig. 5. SEM image of worn surface of JOC filled GE composite at (a) 135 and (b) 540 m abrading distance [56].

filled GE composites. The observed fragmentation of matrix and fiber was relatively low compared to unfilled and JOC filled GE composite [56].

At the 135 m abrading distance, only loosening of the matrix could be observed without the exposure of any fibers (similar to the SiC filled GE composite). At 540 m abrading distance, a little detachment of matrix and fiber can be seen. The improvement in the abrasion resistance in SiC+JOC filled GE composite compared to JOC filled ones may be due to the synergistic effect of hard SiC particles and soft oily JOC (acting as lubricant) which may not have allowed the abrasive particles to cause more wear.

The incorporation of JOC did not show any negative effect on the tensile strength of GE composites. The observed hardness was low in the GE JOC composite compared to that of the unfilled GE composite. Relatively, the JOC filled GE composite exhibited a higher percentage elongation than other composites.

4.1.2. *Jatropha oil cake filled styrene–butadiene rubber composites*

Styrene–butadiene rubber (SBR), because of its excellent abrasion resistant, is widely used in automobile and light truck tyres, belting, flooring, wire and cable insulation, foot-ware and as paper coating. In this study, *Jatropha* oil cake (JOC) powder is used as alternative non-black reinforcing filler from the natural resources in SBR composites. A series of composites have been fabricated by varying the amount of *Jatropha* oil cake (JOC) of approximately 0–20% in SBR. The effect of incorporation of JOC on the optimum cure time of styrene–butadiene rubber (SBR) was investigated by rheological studies. Fig. 7 clearly indicates that influence of JOC is significant on the deformation pattern of the composites. The calculated mechanical properties such as surface hardness, tensile strength, percentage elongation at break and modulus is given in It was noted that there is a noticeable reduction in tensile strength as increase in the JOC content in composites. A significant improvement in % elongation at break was noticed after incorporation of JOC. A steep reduction in tensile modulus with increase in JOC component was noticed. Surface hardness value lies in the range of 60–65 shore A. The tensile data reveals that there is a slight reduction in tensile behavior. However, a slight improvement in tensile modulus and hardness was noticed for all composites.

5. *Jatropha* an alternative carbonized filler to polymer composite

In recent years, agricultural by-products have received increased attention as alternative fillers due to their low cost and abundance. Agriculture fillers can be used in both thermoplastic and thermoset polymer matrices, and the choice of polymer for making composites greatly depends on the intended application of the material. A more economical approach is to incorporate agriculture fillers into composites in the form of particulate fillers, similar to a flour, to replace the use of traditional mineral fillers such as calcium carbonate, mica and talc [57].

Many researchers have studied about the used of agriculture filler such as Khalil et al. used of carbon black and activated carbon from bamboo in polyester composites [58]. Researchers have studied potential of carbonized bagasse filler in rubber product [59]. So many researcher study about carbon black and activated carbon from *Jatropha* seed shell such as [60–63], but no researchers have studied about carbon black and activated carbon from *Jatropha* as filler. On the other hand, carbon black and activated carbon from *Jatropha* are used for purification and water treatment purpose. *Jatropha* as potential to used as alternative as filler on part of plant, such as, seed, seed cake, shell, seed shell because they contain high carbon. From carbonized the fixed carbon will get it. The carbon composition of *Jatropha* part is given in Table 10.

The filler is a material widely used for polymer materials added on to enhance the nature and processing capabilities or to reduce the cost of production. Filler in composite amplifiers is used as polymer resin matrix. Mechanism of filler in increasing strength is by limiting the movement of the polymer chain. Some type of filler is added to the reason increasing dimension stability, anti-oxidants, UV absorbent and coloring.

Particulate fillers are commonly used in the polymer industry to reduce cost, and to improve processing ability, electrical properties, fire retardancy, and mechanical properties. The effect of fillers on the properties of the composites depends on their concentration, their interaction with the matrix, filler size and shape, and filler dispersion [65].

The addition of fillers normally enhances physical properties such as flexural strength, flexural modulus, heat deflection temperature and overall stiffness and resistance of the composite

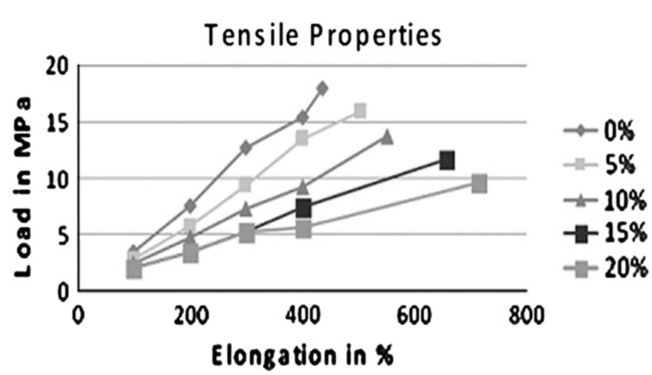


Fig. 7. Effect of JOC content on tensile properties of SBR.
Source: http://psrt.cusat.ac.in/apt10/apt10CD/HTMLS/POSTER/CMP25Swarna.pdf.

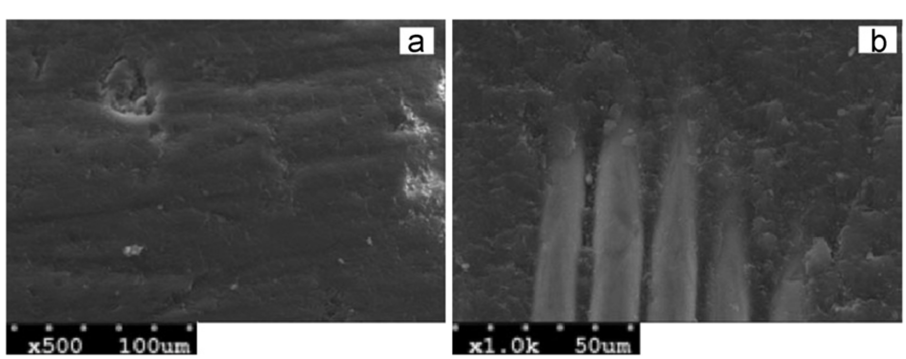


Fig. 6. SEM image of worn surface of SiC+JOC GE composite at (a) 135 and (b) 540 m abrading distance [56].

Table 10
Composition of fixed carbon *Jatropha* plant.

Parameter analysis	Oil cake	Shell	Seed shell/husk
Peoximate analysis			
Moisture (% wb)	08.71	12.35	10.75
Ash (% db)	04.30	14.88	3.97
Volatile matter (% db)	70.92	68.73	71.04
	16.06	16.38	24.99
Fixed carbon (db)	0.01	–	–
Sulfur (% db)			
Ultimate analysis			
Carbon (%)	59.17	–	–
Hydrogen (%)	06.52	–	–
Oxygen (%)	33.93	–	–
Nitrogen (%)	0.38	–	–
Reference	[64]	[9]	[9,11]

to greater loads and at higher use temperature. The dispersion of fillers in a polymer matrix is an important factor affecting the properties of the composite system [66].

6. *Jatropha* as carbon black and activated carbon

Fillers, either powders or fibers are introduced into a broad range of polymers to modify their mechanical properties, thus giving them new application and commercial value. Also it is generally accepted that the nature and degree of interaction between components of the composites also contributes towards the composite properties, as do the properties of the individual components. It is well known that carbon black filled rubber composite has a multiphase system depending on the mobility of rubber molecules, which influences the reinforcement of the composites [67].

Carbon black is a very important material widely used as polymer filler. It is an amorphous form of coal, which usually consist of spherical particles of element carbon. Size of these molecules is than less than few dozen nanometers. Particles create agglomerations with different spatial configurations. Structure and configurations of particles influence properties of carbon black [68].

The genesis of obtaining carbon black is mainly based on incomplete combustion of carbonaceous materials. The main precursors include wood, coal, natural gas and hydrocarbons. The basic production methods for this material include: furnace method, lamp method, and now more widely used plasma method [68], impingement (channel), lampblack, thermal (decomposition of natural gas) and acetylene (decomposition) processes. Carbon blacks are commonly referred to as by the process or the source material from which they are made, e.g. furnace black, lampblack, thermal black, acetylene black and channel black. The different grades from the various processes have certain unique characteristics, but it is now possible to produce reasonable approximations of most of these grades using the oil-furnace process.

Activated carbon was first introduced industrially in the first part of the 20th century, when activated carbon from vegetable material was produced for use in sugar refining. Powdered activated carbon was first produced commercially in Europe in the 19th century, using wood as a raw material, which found wide use in the sugar industry. In the US, the first production of activated carbon used black ash as the source, after it was accidentally discovered that the ash was very effective in decolorizing liquids. Activated carbon has since then been used extensively for this purpose in many industries. In particular, it has been commonly used for the removal of organic dyes from textile waste water. Agricultural by-products and waste materials used for the production of activated carbons include olive stones, almond shells, apricot and peach stones, maize cob, linseed straw, saw dust, rice hulls, cashew nut hull, cashew nut sheath, coconut shells and husks, eucalyptus bark, linseed cake, tea waste ash. Besides these, other sources of activated carbon are sulfonated coal, tyre coal dust, activated bauxite, cement kiln dust, shale oil ash, ground sunflower stalk, etc. All these activated carbons have been successfully used for the adsorption processes [60].

Activated carbons are prepared by physical and chemical activation methods. There are two important advantages of chemical activation over physical activation. One is lower temperature in which the process is accomplished. The other is that the global yield of the chemical activation tends to be greater since burn-off char can be avoided. Acid activation followed by the thermal treatment increases the adsorption capacity to a large extent due to the increased surface area and pore volume [63,69].

During the extraction of biodiesel from *Jatropha* seed, the shell disposal is going to be a concern for environmentalists. Raw *Jatropha* seed shell is toxic [70] and demands appropriate treatment in order not be harmful to human and the environment [60]. One of the possible ways of utilization of this large quantity of toxic waste rich in lignin, is to utilize it as a possible precursor for preparation of activated carbon, a popular adsorbent widely used in industries for variety of applications. Activated carbons are widely prepared from variety of biomass precursors and the industry demands availability of cheap source of biomass that produce good quality activated carbons [61,62]

Jatropha seed and seed cake is potential to be filler in polymer composites, because they have fixed carbon compounds (Table 5). Many researchers study about carbon black and activated carbon from various method but they were studied for purification purpose. The researchers have studied about carbonized of, fruit, seed and seed cake of carbon from *Jatropha. Jatropha seed shell* will be generated in large quantities as an agro-industrial solid waste in the biodiesel production industries. *Jatropha* seed shell constitutes nearly 80% of the dried vegetable [63].

Karthikeyan et al. [60] have studied activated carbon from *Jatropha* seed shell with activated by chemical, the result summaries in Table 11. The result shows that the bulk density values are on the lower side, which may be due to highly branched and porous carbon with more void space. Except H_2SO_4, $ZnCl_2$, Na_2CO_3 and $NH_4S_2O_8$ carbon all the carbons found to be basic in nature. Due to the presence of highly porous organic matter in *Jatropha* shell, the quantity of volatile matter shows a higher trend. High value of ash and volatile matter reduces the quantity of fixed carbon. Kumar and Chinnaiya [63] also used *Jatropha* seed shell as

Table 11
Jatropha seed shell waste activated carbon properties.

Propertis	HCl	H_2SO_4	$ZnCl_2$	Na_2SO_4	Na_2CO_3	$CaCO_3$	$CaCl_3$	$H_2SO_4+NH_4S_2O_8$	$H_2SO_4+H_2O_2$
pH	9.55	4.67	6.60	8.50	5.74	9.20	7.16	6.85	7.05
Moisture content, %	11.00	2.00	8.00	10.00	10.00	16.40	8.20	9.60	10.10
Ash content, %	7.42	11.94	19.57	17.77	14.00	10.57	13.07	8.67	10.85
Volatile matter, %	30.00	26.70	27.50	31.20	20.00	24.20	27.80	31.30	34.20
Fixed carbon, %	69.00	73.50	59.80	73.10	73.80	72.10	69.70	81.00	84.30
Conductivity, mS/cm	0.22	0.10	0.61	0.13	0.33	0.37	0.24	0.19	0.42
Specific gravity, S	1.25	1.33	1.49	0.89	1.10	1.48	1.32	1.88	1.37
Bulk density, D	0.44	0.39	0.44	0.40	0.63	0.29	0.39	0.28	0.45
Porosity (S-D/S) $\times$100, %	44.20	53.08	69.48	62.56	64.55	64.86	72.15	61.26	72.34
Matter soluble in water, %	1.84	1.06	1.74	2.12	1.41	1.22	0.72	1.02	1.20
Matter soluble in acid, %	1.25	1.08	1.62	1.42	0.94	0.74	0.92	1.41	1.91
Surface area, m^2/g	1195	709	590	456	629	408	1064	664	751
Iodine number, mg/g	1143	668	899	412	589	368	998	612	723
Sodium, w/w%	15.00	5.50	8.00	15.00	5.50	8.00	6.40	5.50	8.40
Potassium, w/w%	10.60	5.70	3.10	6.10	2.00	5.00	5.00	7.60	7.10
Iron content, w/w%	1.40	1.20	1.00	0.90	1.10	1.20	0.80	1.00	1.20
CCl_4 activity	0.36	0.55	0.59	1.14	1.19	0.52	0.72	1.32	1.19
Phenol adsoption capacity, mg/g	5.21	2.85	3.62	1.22	2.28	0.80	4.20	3.08	2.64
Yield, %	42	39	44	32	55	37	52	62	32

activated carbon by chemical activation. Duan [61,62] has investigated activated carbon *Jatropha* seed shell comparison by conventional heating and microwave heating, and optimization using response surface methodology (Table 12).

To utilize *Jatropha* fruit shell, biomass waste, for the preparation of activated carbon by simple thermo-chemical activation using NaOH as an activating agent has studied by Kumar and Chinnaiya [63]. The effects of impregnation ratio of reagent to char, activation temperature and activation time on iodine and methylene blue numbers of the activated carbon were studied in order to obtain high adsorption capacity and surface area of the product. Subsequently, the physico-chemical characteristics of the activated carbon, obtained by optimum conditions, were also determined.

Palanivel et al. [70] used activated carbon from *J. curcas* pods for removal of reactive dye, RBBR from textile effluent. This may provide the solution for cleansing of *Jatropha* wastes and their reutilizations which in turn will protect the environment from the pollution of dye. Therefore, in this study dye adsorption efficiency, adsorption kinetics and adsorption isotherm models of *Jatropha* activated carbon were performed. Bench scale experiments and desorption studies were also carried out to understand the reusability of activated carbon.

Table 12
Pore size distribution, total pore volume and average pore size of activated carbon from *Jatropha* seed shell.

Sample	Surface area, m^2/g	Pore volume, cm^3/g	Avarage pore, nm
Char	480	0.42	3.50
Conventional heating with CO_2	748	0.53	2.85
Conventional heating with CO_2	1207	0.86	2.86
Microwave heting with steam	1350	1.07	3.10
Microwave heating with CO_2	1284	0.87	2.71

7. Nanotechnological advancement in j*atropha*

The area of nanotechnology encompasses synthesis and characterization of nanoscale materials, the understanding and the utilization of their potential applications. Biological entities and inorganic materials have been in constant touch with each other, ever since inception of life on the planet Earth. Nanoparticles have gained wide recognition in variety of commercial and industrial applications over the years such as structural applications, skincare products, information and communication technology, biotechnology and environmental monitoring instrumentation [71]. Biosynthesis of nanoparticles has received considerable attention due to the growing need to develop environmentally benign technologies in material synthesis.

Nanoparticles are particles that have one dimension that is 100 nm or less in size. The properties of many conventional materials change when formed from nanoparticles. This is typically because nanoparticles have a greater surface area per weight than larger particles; this causes them to be more reactive to certain other molecules.

Particularly the use of latex, proteins and phytochemical, etc. for synthesis of metal nanoparticles has dual advantage that, they not only act as a reducing agent but also as capping agents and deter the particle aggregation [71]. The major constituent of the latex of *Jatropha* are curcain (an enzyme) [21], curcacycline A (a cyclic octapeptide) [72] and curcacycline B (a cyclic nonapeptide) [73].

Bar et al. [74] reported a green method for the synthesis of silver nanoparticles using aqueous seed extract of *Jatropha* and no toxic chemicals are used as reducing and stabilizing agent during the synthesis. Formation of stable silver nanoparticles at different concentration of $AgNO_3$ gives mostly spherical particles with diameter ranging from 15 to 50 nm. The resulting silver particles are characterized using HRTEM, XRD and UV–vis spectroscopic techniques. XRD study shows that the particles are crystalline in nature with face centered cubic geometry.

Hudlikar et al. [75] have synthetis ZnS and TiO_2 nanoparticles from *Jatropha* latex. They found that 0.3% latex solution prepared from *Jatropha* latex and 2.5 mM aqueous solution of zinc acetate was found to be optimum to get maximum yield of ZnS nanoparticles. The reduction of $TiO\cdot(OH)_2$ to TiO_2 using 0.3% aqueous extract prepared from *Jatropha* latex, TiO_2 nanoparticles synthesized can be broadly categorized as, first having diameter from 25 to 50 nm with mostly spherical shape and the rest having some larger and uneven shapes. Fig. 8 shows Transmission Electron Micrograph (TEM) images of TiO_2 and ZnS nanoparticle from *Jatropha* latex.

Shriram [7] has investigated the particles size and nanoparticle form *Jatropha* latex. The spherical in shape is shown in Fig. 9a and the particle size distribution was measured using a DLS (Dynamic light scattering) unit as shown in Fig. 9b. Particles formed were of monodisperse type showing diameter in the range of 5–17.5 nm. The results of DLS and TEM are in agreement with each other, because the as synthesized solutions were used for characterization. Some difference in particle size is observed when nanoparticles are isolated and redispersed. Particle formed showed excellent reproducibility and uniformity (Fig. 9).

8. Applications of *Jatropha* biomass

Plant biomass has attracted attention as a chemical resource for replacing fossil fuel resource, because of the renewability and the carbon neutral nature. Many efforts have been devoted to utilizing the waste biomass as valuable chemical resource for synthesizing polymers. Wood can be decomposed and liquefied by reaction with phenols or alcohols. The liquefied wood has high reactivity because of the large amount of phenolic OH groups and alcoholic OH groups. The liquefied wood has more potentiality as a resource for other valuable biomass-based resin families.

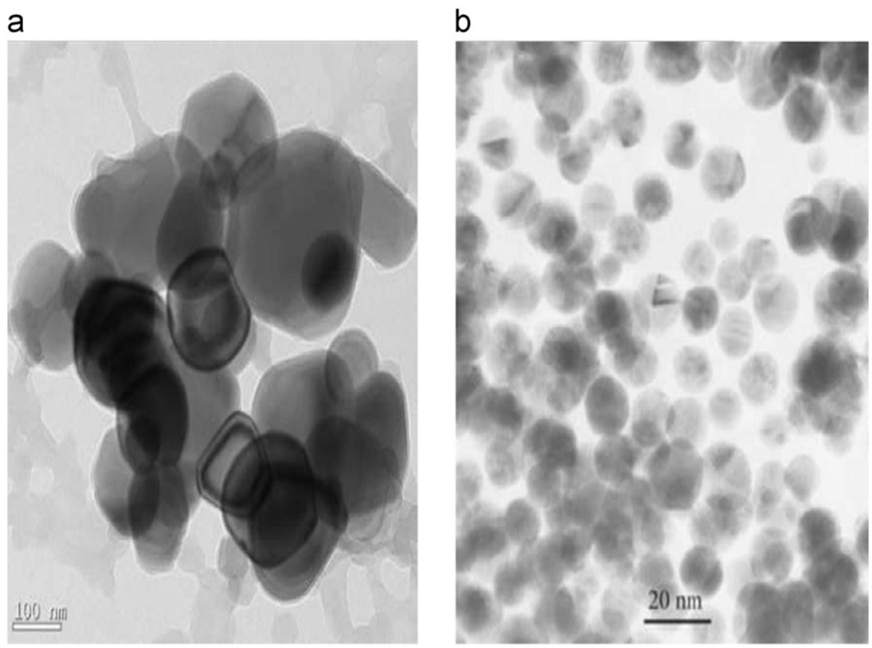


Fig. 8. TEM of (a) TiO_2 and (b) ZnS nanoparticles from *Jatropha* latex.

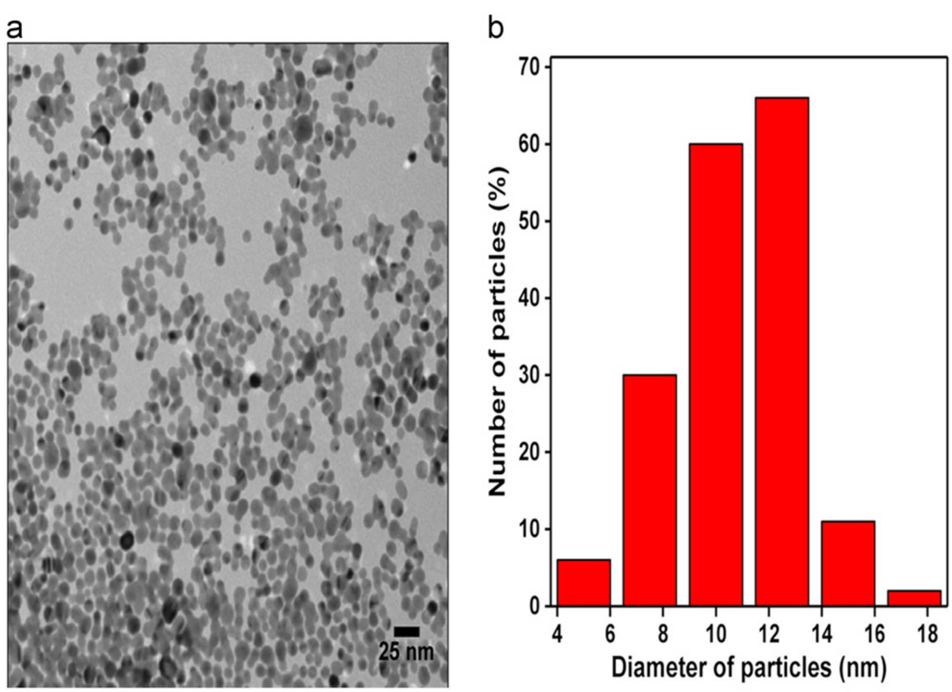


Fig. 9. (a) Transmission electron micrograph (TEM) of lead nanoparticles showing spherical shape. Particle size (b) distribution of latex stabilized lead nanoparticles.



Fig. 10. *Jatropha* soap in Tanzania.

The most common technical applications of the industrial proteins, e.g. adhesives, coatings, and surfactants have been reported by Vaz et al. [76]. Important functional properties that are related to technical applications are solubility, film forming properties, foaming properties, emulsifying properties, and adhesive properties.

Epoxy resins have good mechanical and adhesive performances, and therefore, they are widely used in various fields, such as adhesives, coating resins, and matrix resins of composites. However, in view of environmental safety, alcohols would be better chemicals than phenols as the liquefaction solvents [77].

Jatropha is a woody plant and, therefore, its twigs, branches and stems can be used for a number of purposes, especially as fuel, sticks and poles. Unfortunately, the twigs remain green for a long time and are difficult to dry out and thus burn. If used as poles, they have a tendency to sprout. However, in some countries, the live pole is used to support vines such as the vanillin plant. The fruit is normally toxic, unless treated, but there are varieties that produce non-toxic fruit. If it can be detoxied cheaply, or the oil extracted from toxic free varieties, it could be used in food preparation and the seed cake used as animal feed. Latex and oil from the plant have medicinal, pesticidal and mollusk control properties. Tannin can be extracted from the bark and nutshell, etc. and used to treat leather. A varnish can be made from the oil and the leaves are a feedstock for silk worms [19].

Jatropha oil is similar to sun flower/palm oils and tallow (animal fat). It contains a fatty acid and one of its uses is as a raw material for soap making (Fig. 10). *Jatropha* oil has been used commercially for soap manufacture for decades, both by large and small industrial producers. For example, in India it is used by a large industry (Hindustan Lever). In Zimbabwe, soap is produced by small informal industries in rural areas using plant oil, but one large manufacturer is interested in using *Jatropha* oil as a substitute for tallow. However, the monthly requirement of this industry alone is 2000 l of oil. To supply this demand, would require the equivalent of about 20,000 ha. Clearly, the present area, an estimated 2000 ha equivalent, is only about 10% of the required area to meet this demand alone [19].

By applying chemical know-how these oleochemicals feedstocks are converted into a wide range of chemical products for use in cosmetics, paints and inks, lubricants, biofuels, textile and leather, plastics, rubber, soaps and detergents, pharmaceuticals and many other industries.

Many potential outlets for non-food oilseed have been already identified. The potential of these products is very high in comparison with other bio-based products. Some of the more traditional like candles, paints and linoleum are already well developed, while some others are still being explored and have not yet achieved critical market penetration. *Jatropha* oil appears to have a significant potential as a raw material for the industrial applications as because it is renewable and non-edible.

8.1. *Jatropha* as resin

Polymerization is one of the most important industrial processes. Resins and emulsion are two main classes of polymer. Alkyd resins are by far the most important class of coating resins. It is estimated that alkyd resins contribute about 70% to the conventional binders used in surface coating today. Fossilized resins have attracted considerable interest in the past few decades since the important contribution they can make to crude oils became known [78]

Alkyd resins have gained importance in coating and paint industries due to its low cost because of relatively inexpensive raw material usage in the formulation and high solubility in less expensive solvents. Alkyd resins are employed commonly in decorative paints, air drying and stoving paints, industrial paints, inks, machine toll finishes, and marine topside and weather work paints.

Alkyd resins are typically made through condensation polymerization of natural oils or fatty acids with polyhydric alcohols such as pentaerythritol, glycerol or trimethylol propane and dibasic acids such as phthalic anhydride and isophthalic acid. Alkyd resin is a highly branched polymer with polyester backbone [79].

Jatropha oil appears to have a significant potential as a raw material for the industrial applications because it is renewable and non-edible. The cost competitiveness of *Jatropha* oil compared to other oils such as soya, rapeseed, etc. [79] has attracted the industrialist and academicians to explore this material as a material for the production of alkyd resins. In recent years, polymers developed from the renewable resources, especially plant oils, have attracted much attention due to the economic, environmental and societal advantages [80].

The clear oil has also been used for illumination, lubrication, polish, varnish, candles and insecticide. Although seed oils are increasingly used to produce biodiesel, *Jatropha* oil is not as competitive as soybean and rapeseed oils. Also, since *Jatropha* oil contains a high percentage of monounsaturated oleic and polyunsaturated linoleic acids indicating a semi-drying property, it is worth investigating the possibility of using the oil to prepare alkyd resin [81].

The properties of composite materials, in general, are superior in many respects, to those of the individual constituents. This has

provided the main motivation for the research and development of composite materials. The properties of polymeric composite materials are mainly determined by three constitutive elements: the resin, the reinforcement, such as particles and fibers, and the interface between them. According to the reinforcement used, composite materials can be broadly classified into fiber reinforced composites and particle-based composites [82]; natural fiber composites with plant oil-based resin [83]. Researchers prepared oil-modified alkyd resin from crude castor oil and studied its physico-thermal properties [78].

The utilisation of an alcohol and acid for the preparation of alkyd resin resulted the name 'alkyd'. Alkyd resins are typically made through condensation polymerisation of natural oils or fatty acids with polyhydric alcohols such as pentaerythritol, glycerol or trimethylol propane and dibasic acids such as phthalic anhydride and isophthalic acid. Alkyd resin is a highly branched polymer with polyester backbone.

Since the natural oils and fatty acids are renewable raw materials, alkyd resin obtained from these natural oils can be classified as green binder compared to acrylic binders whose building blocks stem from mineral oil [79].

Alkyd Resin based on *Jatropha* and Rapeseed oils using glycerol, phthalic, and maleic anhydride were synthesized to obtain the resins suitable for electrical applications has investigated by Patel et al. [84]. These resins were characterized for the physical and electrical properties [84]. The alkyd resins from *Jatropha* oil and Rapeseed oil were synthesized by esterification process using glycerol and anhydrides. The mole ratio of *Jatropha*/rapeseed oil was taken considering the 48% oleic acid, since it is major content of oils. The molecular weight of fatty acid was taken as 326 and the content of anhydride was taken considering its purity 99%. Odetoye et al. [81] have reported the preparation and evaluation of *Jatropha* seed oil alkyd in order to further highlight its potential industrial significance. The comparisons of physical and electrical properties of varnishes prepared from alkyd resin from *Jatropha* and Rapeseed oil with syntholacl-60 commercial resin as available in market are shown in Table 13 [79]. Shah [85] study results reveal that *N,N*-bis(2-hydroxyethyl) *Jatropha* fatty amide derived from *Jatropha* oil can be used successfully as a cross-linking agent in baking type coating compositions for the acid functional acrylic resins.

8.2. *Jatropha* as adhesive

There have been several attempts to replace part of the petroleum-derived phenolic compounds in wood bonding adhesives with phenolic-type compounds obtained from renewable sources. Principal among these efforts is the development of adhesives from tannin [86–88] lignin [89,90], and protein [91]. Tannin-based adhesives, lignin-based adhesive, and protein-based adhesive have in the past been heavily fortified with urea, urea-formaldehyde (UF), phenol–formaldehyde (PF), and resorcinolformaldehyde (RF) with encouraging results. An adhesive or stick on is a material, usually in a liquid or semi-liquid state, that adheres or bonds items together. Adhesives come from either natural or synthetic sources.

Tannins are polyphenolic compounds of vegetable tissues with different chemical structures depending on their origin. They are usually classified in condensed and hydrolysable tannins [92]. Condensed tannins have flavanol units in their structure, while hydrolysable ones are composed of a molecule of sugar, generally glucose, joined to phenolic [86]. Besides classical applications of tannins in hide tanning and wine preparation,

Table 13
Comparison of physical properties of alkyl resin and vanish.

Sr. No	Properties	Specified value in IS 10,026	Alkyl resin prepare from *Jatropha* oil	Alkyl resin prepare from rapeesed oil	Commercial alkyl resin (Syntolacl-60)
A	Alkyl resin				
1	Density		1.26	1.01	1.14
2	Viscosity		166,000 cps	1250 cps	41,600 cps
3	Nonvolatile matter		92.71%	70%	98.96%
B	Varnish based on alkyl resin				
1	Density		1.075	0.94	1.08
2	Viscosity		50 cps	50 cps	200 cps
3	Nonvolatile matter		50%	50%	50%
4	Drying time in thin film	Non tacky	4 h at 130 °C	3 h at 120 °C	3 h at 120 °C
5	Flas point, °C	23 °C min	25 °C	36 °C	25 °C
6	Ability to cure in conciderable thikness		S.2, U.2,I.5, I.42	S.2, U.2,I.5, I.42	S.2, U.2,I.5, I.42
7	Chek for resoftening	Not worse than w_2	W.2	W.2 no change and few bubbles	W.2 no change and few bubbles
8	Reaction with copper	Shall not react	Does not react	Does not react	Does not react
9	Felxibility	No crack	No crack observe	No crack observe	No crack observe
10	Effect of varnish on enamelet wires	Pencil hardness not softer than H	Passed test	Passed test	Passed test
11	Resistance of transformer oil, after 48 h at 100 °C (A) visual examination	No evidence of attack	No softening, blistering, wringkling, this integration or seperation of varnish film	No softening, blistering, wringkling, this integration or seperation of varnish film	No softening, blistering, wringkling, this integration or seperation of varnish film
		No evidence of attack	Slightly yellow color of oil	Slightly yellow color of oil	Slightly yellow color of oil
	(B) Acidity of oil before and after aging	0.4 KOH/g max	(b) Acidity: nil before and after	(b) Before: 0.0012 mg KOH/g, after: 0.03 mg KOH/g	(b) Acidity: nil before and after
	(C) Sluge value of oil before and after aging	0.1% max	(c) Nil before and after	(c) Before: 0.01%, after: 0.015%	(c) Nil before and after
12	Effect of heat aging on flexibility (100 h at 110 °C)	No visable change or detachment of film	No crack observed	No crack observed	No crack observed

Adopted from [79].

several new emerging applications are in adhesive industries for replacing hazardous phenol in novolac resins [93], for reducing gelation, pressing time and formaldehyde emissions of resole resins [92] or for tannin-based adhesives manufacture [89,94].

Lignin can be incorporated into PF resin mainly in three ways: (1) it can be reacted with formaldehyde to provide methylol functionalities and then added to PF resins, where lignin acts as an extender; (2) condensing lignin directly with phenol and formaldehyde; and (3) derivatizing lignin either with phenol or formaldehyde to enhance its reactivity toward PF resins [95].

Today's wood adhesives range from formaldehyde-based resins to latex-based systems, all being fossil based. A sustainable alternative to these adhesives, which has been proposed during the last years, is adhesives based on proteins, e.g., wheat gluten or soybean proteins [91].

Jatropha proteins can be obtained from the press cake and the leaves [24]. Proteins are the major components of the *Jatropha* seed cake. A number of proteins, such as soy protein, gelatin and casein, have been commercially produced for decades for food and technical applications. However, *Jatropha* seed contains curcin and phorbol esters, which are toxic compounds [96]. These compounds are also found in the seed cake, which limit the uses of *Jatropha* seed cake for food and feed applications, without further detoxification. Protein from *Jatropha* press cake has used for technical applications an emulsifier, coating, bioplastic, foaming agent or adhesive [24] as shown in Table 14.

Makkar et al. [18] have studied comparative evaluation of non-toxic and toxic varieties of *Jatropha* for chemical composition, digestibility, protein degradability and toxic factors. They have extracted the phenol and condense tannin meal, shell and seed shell from varieties of *Jatropha*, the result is given in Table 15.

Much researchs have been conducted to extract protein from *Jatropha* meal in combination with a detoxification process to produce protein concentrates or protein isolates for animal feed. *Jatropha* meal utilization for non-food applications, such as adhesives, coatings, and surfactants, has not been explored so far. The most common technical applications of the industrial proteins, e.g. adhesives, coatings, and surfactants have been reported by Vaz et al. [76]. Hamarneh et al. [97] investigate the possibility to extract proteins from the *J. curcas* seeds, using the principle of isoelectric precipitation. They tried to apply these proteins in wood adhesive formulations based on the previously reported polyketone systems. Isolation, stability and bioactivity of *J. curcas* phorbol esters reported by Roach et al. [98]. Arabinogalactan protein from *J. curcas* L. seeds as TGFβ1-mediated inductor of keratinocyte in vitro differentiation and stimulation of GM-CSF, HGF, KGF and in organotypic skin equivalents [12]. Although, several researcher have studied extracted protein [24], tannin (Makkar et al., 1997), probhol ester [98], etc., from part of *Jatropha* plant, it is need to develop these compounds for industrial purpose.

Table 14
Jatropha seed protein adhesive properties [24].

Adhesive formulation	13% Casein	13% DOPC protein	13% PC protein
Solvent	Water	0.055 M NaOH	0.55 M NaOH
Viscosity [cP] direct	888 ± 87	931 ± 115	4338 ± 442
Viscosity [cP] 2 days	116 ± 14	383 ± 6.2	170 ± 3.5
pH	7	8	8
Color	Yellow	Brown	Brown
Set time (min)	2.5 ± 0.7	1.25 ± 0.4	2.25 ± 0.35
Open time (min)	3.5 ± 0.7	8 ± 2.83	9.5 ± 0.7
Adhesion (60% RH)	+++	+++	++
Adhesion (water)	–	–	+

8.3. Oil for soap production

In former times, the seed oil was used mainly for soap production. Production of soap is one of the most economically attractive uses of *Jatropha* oil. The glycerin by-product of the trans-esertification process can be used to make a high quality soap, or it can be refined and sold at a range of prices, depending on its purity, to be used in an immense range of products, including cosmetics, toothpaste, embalming fluids, pipe joint cement, cough medicine, and tobacco (as a moistening agent). The soap has positive effects on the skin and is therefore marketed for medicinal purposes. *Jatropha* oil is used mainly in the manufacture of high quality soap. According to the IPGI report, pressing of 12 kg of seeds yields 3 l of oil that is then transformed into soap, 28 pieces of soap of 170 g each, which is 4.76 kg. This takes 5 h of work (estimated) [99].

Traditionally, *Jatropha* soap has been made by mixing *Jatropha* seed and oil with sodium hydroxide to produce washing soap. The soap is believed to contain natural oil that helps to protect the skin against rashes, fungus, and other skin problems such as ringworms especially in children. The traditional soap-making process is very labor-intensive, producing small amounts of relatively poor-quality soap. When machine-produced *Jatropha* oil products are used, either alone or in combination with other local plant oils such as shea butter, larger amounts of a more refined soap are produced.

8.4. Oil as biodiesel

The biofuels industry is growing rapidly as a result of high petroleum prices and increasing concerns about global climate change. *Jatropha* oil can be used as fuel in diesel engines directly and by blending it with methanol [26]. More recently, the clear oil expressed from the seed has been suggested for energetic purposes as a substitute for diesel. Most importantly, it is significant to point out that the oil of *Jatropha* is a viable alternative to diesel fuel since it has desirable physico-chemical and performance characteristics as diesel. The obtained biodiesel from *Jatropha* oil after transesterfication confirms the standard requirements of

Tabel 15
Total phenol, tannins and condensed tannins in meal, shell and seed shell of jatropha varieties (on dry matter basis).

Item	Variety								
	Cape Verde		Nicaragua		Ife-Nigeria			Non-toxic Mexico	
	Kernel	Shell	Kernel	Shell	Kernel	Shell	Seed shell	Kernel	Shell
Total phenols (% tannic acid equivalent)	0.36	3.0	0.29	2.8	0.31	3.1	0.18	0.22	4.4
Tannin (% tannic acid equivalent)	0.04	2.2	0.03	2.0	0.0	2.2	0.01	0.02	2.9
Condensed tannins (% leucocyanidin equivalent)	Non detectable	Non detectable	Non detectable	Non detectable	Non detectable	Non detectable	Non detectable	Non detectable	Non detectable

American and European countries [100]. Cars and trucks could be run with *Jatropha* oil without requiring much change in engine design. However, there are several points of view that differ considerably regarding *Jatropha*'s suitability as a substitute for petroleum products. The seed oil of *Jatropha* may not be used directly in engines because of lower cetane number and higher viscosity at low temperatures as compared to conventional diesel. This may be due to the fact that, the diesel is a hydrocarbon with 8–10 carbon atoms per molecule whereas *Jatropha* seed oil has 16–18 carbon atoms per molecule. The transesterification process was adopted to convert *Jatropha* seed oil into biodiesel.

Transesterified oil can be used in any diesel engine. This process is normally carried out in centralized plants since the small-scale economy of transesterification has not been determined. During the process, methanol, a highly flammable and toxic chemical, has to be used. This requires explosion-proof mixing equipment which might not always be available in certain developing countries.

8.5. Paper from Jatropha

Paper from *Jatropha* fiber has published [101]. The fibers are made from the *Jatropha* bark and/or wood. Bark alone gives a greenish color. Wood or bark is left soaking in water for some days and then pounded to obtain the fibers. First the fibers are suspended in water to form a slurry in a large vat. The mold is a wire screen in a wooden frame (somewhat similar to an old window screen), which is used to scoop some of the slurry out of the vat. The slurry in the screen mold is sloshed around the mold until it forms a uniform thin coating. The fibers are allowed to settle and the water to drain. When the fibers have stabilized in place but are still damp, they are turned out onto a felt sheet which was generally made of an animal product such as wool or rabbit fur, and the screen mold immediately reused. Layers of paper and felt build up in a pile (called a 'post') then a weight is placed on top to press out excess water and keep the paper fibers flat and tight. The sheets are then removed from the post and hung or laid out to dry. A step-by-step procedure for making paper with readily available materials can be found online.

When the paper pages are dry, they are frequently run between rollers (calendared) to produce a harder writing surface. Papers may be sized with gelatin or similar to bind the fibers into the sheet. Papers can be made with different surfaces depending on their intended purpose. Paper intended for printing or writing with ink is fairly hard, while paper to be used for water color, for instance, is heavily sized, and can be fairly soft.

The wooden frame is called a "deckle". The deckle leaves the edges of the paper slightly irregular and wavy, called "deckle edges", one of the indications that the paper was made by hand. Deckle-edged paper is occasionally mechanically imitated today to create the impression of old-fashioned luxury. The impressions in paper caused by the wires in the screen that run sideways are called "laid lines" and the impressions made, usually from top to bottom, by the wires holding the sideways wires together are called "chain lines". Watermarks are created by weaving a design into the wires in the mold. This is essentially true of Oriental molds made of other substances, such as bamboo. Hand-made paper generally folds and tears more evenly along the laid lines [101].

8.6. Other use

Jatropha oil is also used to soften leather and lubricate machinery (e.g. chain saws). If seed cake is available in large quantities, it can also be used as a fuel for steam turbines to generate electricity. Apart from the biodiesel application, the oil finds the application in cosmetic industries. The extraction of the biodiesel after transesterification of the seed oil leads to two main by-products that is glycerol and press or oil cake. Glycerol has many useful industrial applications as a raw material for the synthesis of 1, 3 propane-diol and other polymeric materials [29,95]. The bark of *Jatropha* contains tannin. It can also have the honey production potential as the flowers can attract bees.

9. Conclusions

Green materials are the asset of the future. There is immense opportunity in developing new bio-based products, but the real challenge is to design sustainable bio-based products. New environmental regulations and societal concern have triggered the search for new products and processes that are compatible with the environment. The corporation of bio-resources in composite materials can reduce further dependency on petroleum reserves.

J. curcas L. is a versatile plant with several actual and potential uses. Development of *Jatropha* in the world gives various applications. The *Jatropha* plant can become globally competitive due to the fact that it belongs to a non-edible category and does not compete with food.

Each part of *Jatropha* plant has many chemicals with various compositions. We can develop several products beside medicine, food, cosmetic, etc., also application for biocomposite, but it is still less. The oil from the seed of the plant is potentially the most valuable end product. Beside used as biodiesel, soap, etc., the application for technical as resin and adhesive have been investigated. The seed cake contains proteins such as curcin and probhol ester, this compound can be used as adhesive. Leaf and stem of *Jatropha* could be extracted to resin and another purpose.

From the above discussions, it is clear that the *Jatropha* plant has capabilities to provide the products for different applications apart as a diesel substitute which needs to be captured and improved. The research on the utilization of the by-products of *Jatropha* namely seed husk, seed kernel, glycerol, etc. in the material manufacturing area needs to be explored.

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